National Aeronautics and Space Administration

Toward IVHM Prognostics

Kevin Walsh

NASA Dryden Flight Research Center

NASA Aviation Safety Program

Aviation Safety Technical Conference

October 10 - 12, 2007

St. Louis, Missouri

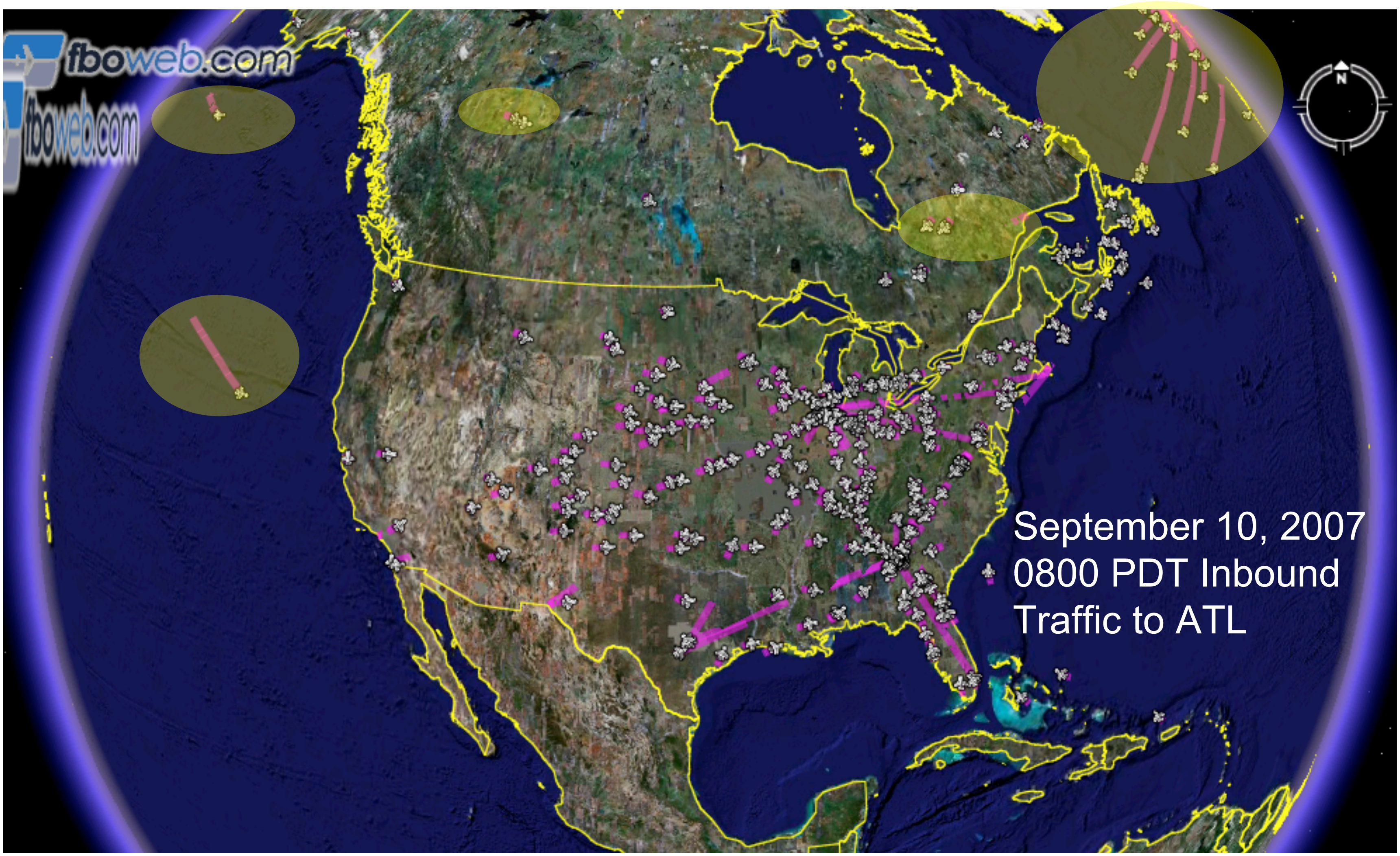
www.nasa.gov

Table of Contents

- **Aircraft Operations – Today's way of doing business**
  - Examples
  - Data collection, analysis, and effects on operations
- **Prognostics**
  - Vision
  - Translation – Different goals between NASA and Industry
  - Dryden's role
- **NASA's instrumentation data-system rack**
- **Data mining for IVHM**
- **NASA GRC's C-MAPSS generic engine model**
  - Conversion to install on Omega System
  - Test engine model using past flight data
  - Demonstrate model operation using real-time input data
- **Concluding Thoughts**

Aircraft Operations – Real Time

One Airport's Worth of Inbound Traffic



Aircraft Operations

Today's Way of Doing Business

- **Aircraft operations** – The daily application of aircraft flights to meet a customers needs whether it be commercial or military
  - Regional – Short flights usually less than 3 hours, many takeoffs and landings per aircraft
  - Transcontinental – Flights 3-5 hours across the United States
  - Oceanic – Flights traveling across either ocean lasting 7+ hours

In a nutshell how many times a day do airframe/engines see cycles?

Aircraft Operations

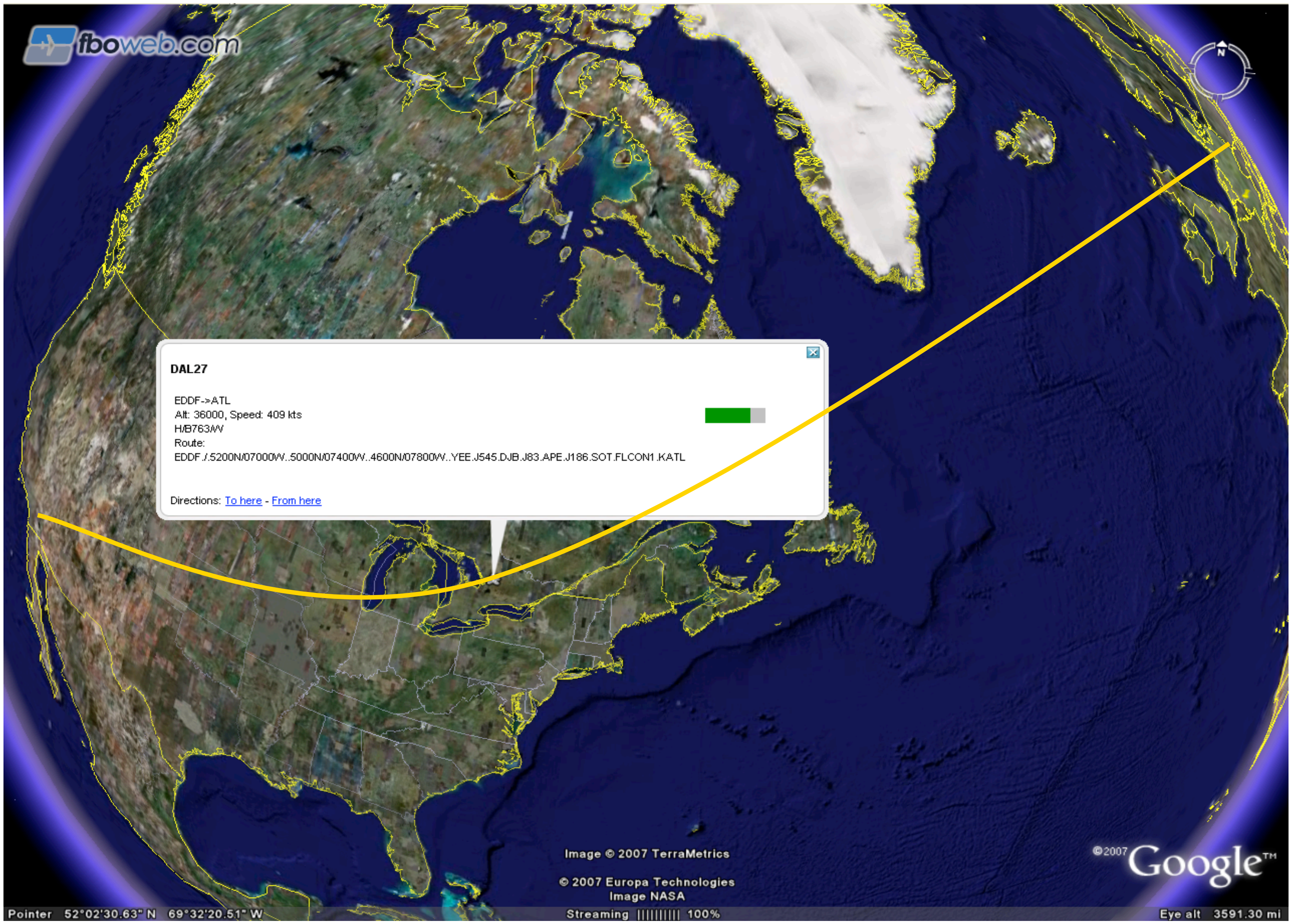
Today's Way of Doing Business – Regional

Aircraft Operations

Today's Way of Doing Business – Transcontinental

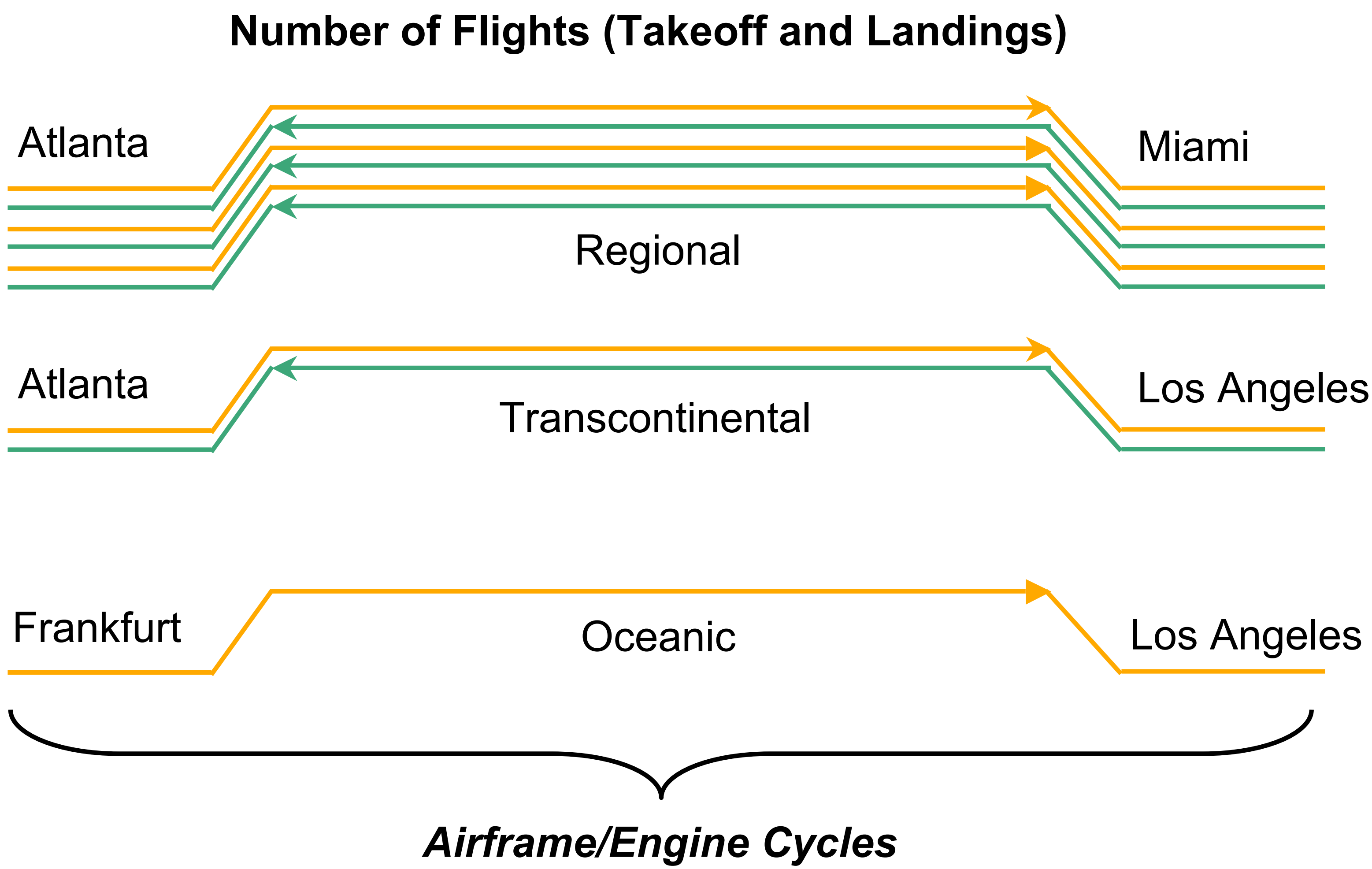
Aircraft Operations

Today's Way of Doing Business – Oceanic



Aircraft Operations

Airframe/Engine Daily Usage



Aircraft Operations
All This Data!!!

- **Data collection – typically done in a variety of ways**
  - Snapshot data down linked in real-time
  - Onboard low resolution recorders
  - Event capturing with small amounts of transient support data, roughly 30 - 60 seconds duration
  - Use of current sensor suite on engine
- **Analysis and decision making**
  - Performed by engineers and maintenance personnel either centrally or on aircraft as troubleshooting task
- **Effects on operations**
  - In today's world, slow and cumbersome
  - Time for analysis to reach aircraft can be minutes to days
  - Downtime costs airlines $$$$
  - Prognostics is minimal, fault detection and accommodation decisions are reactionary

Prognostics
Vision

- **Now:**
  - Develop algorithms capable of performing Feature Extraction (FE) of real-time and post-flight event data and embed these within the avionics suite
  - Ensure flight crew, maintenance personnel and scheduling has access to critical FE data prior to flights not during
  - Data mining techniques that create virtual sensing capabilities
- **Future:**
  - Consideration for greater aircraft/propulsion integration
  - Look at what the airframe imposes on the engine
  - New sensor technologies

Prognostics

The Decoder Ring

- **Performance Enhancement (1)**
  - Better fuel economy, lower emissions
- Life Extension (2)
  - Increase Time On Wing (TOW)
- Damage Adaptability (3)
  - Ways to utilize engine when damage has occurred, continued use while flying, ability for limited use.

- Industry's Interest – Safety/Economic Benefit
- NASA's Interest - Safety

Industry Interest

NASA Interest

- Industry's Interest – Economic Benefit
- NASA's Interest - Environment

Benefits of Implementing IVHM Technologies

Aircraft Categories

In Production Aircraft

Primarily, develop algorithms that can be embedded into existing systems. Secondary, develop hardware that can "Buy Its' Way On" via retrofit into existing aircraft and incorporated into aircraft under production:

- On wing trending and diagnostics (1/2)
- Performance/maintenance feature extraction for storage and transmission (1/2)
- Performance enhancing control algorithms (1/2)
- Damage adaptive AFCS/ATS coupled control and indication (3)
- Intelligent pilot advisories (1/2/3)
- Neural network control and maintenance learning techniques (1/2)

Legacy Aircraft

Most practical, develop algorithms that can be embedded into existing systems to support:

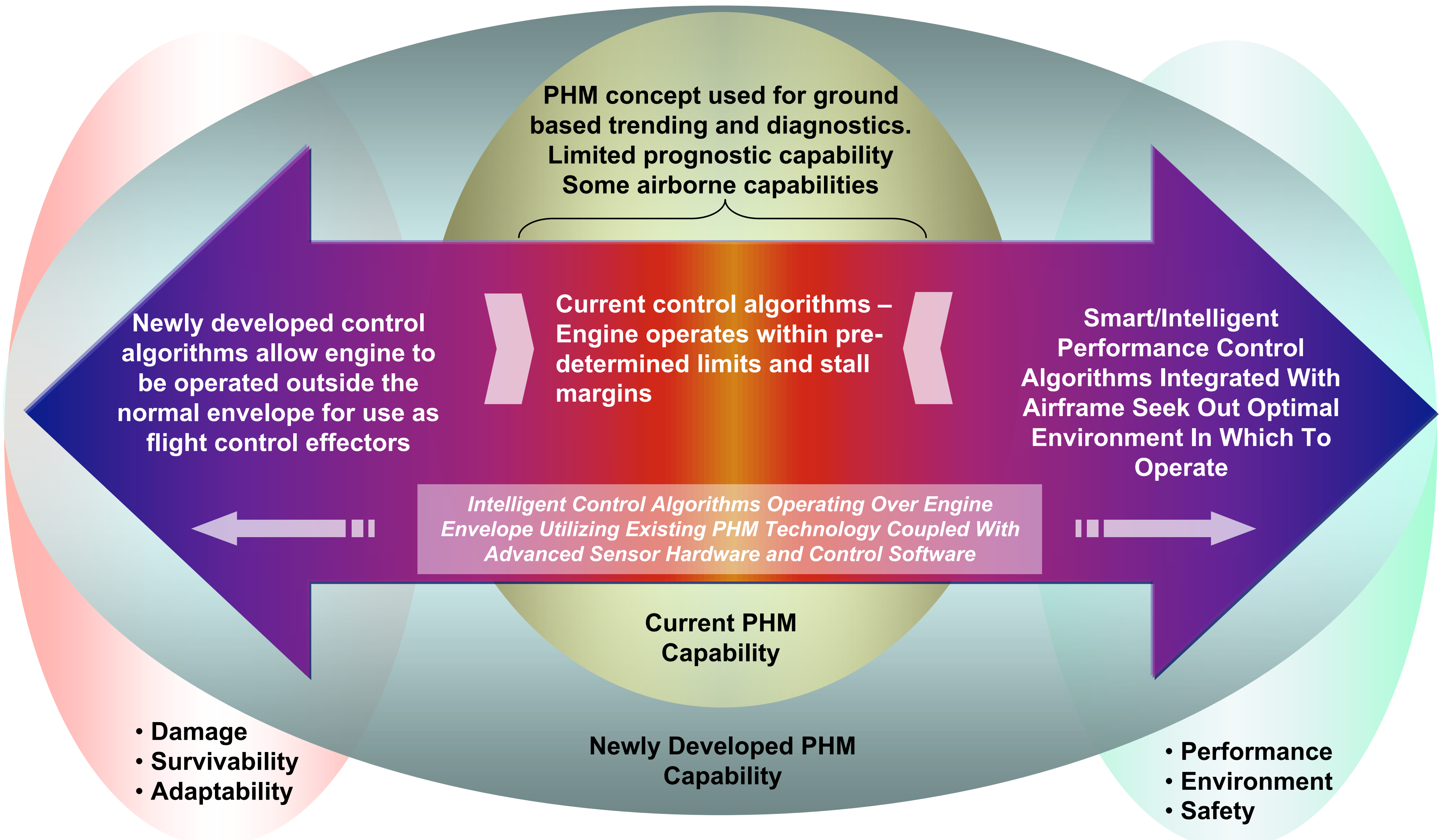
- On wing & ground based trending and diagnostics (1)
- Performance enhancing control algorithms (2)
- Damage adaptive pilot fly-to indications (3)

Aircraft Under Development

- New sensors. (1/2/3)
- New hardware (1/2/3)
- Self learning, teaching and adaptive techniques for:
  - Control, normal, abnormal (i.e. wind shear, damage, turbulence)
  - Prognostics for maintenance (pre-trend to removal)
  - Normal maintenance
- Neural network control and maintenance learning techniques (1/2)
- Transition to space techniques. (1/2/3)

Prognostics and Mitigation

The Big Picture - Future



Dynamic PHM Oriented Algorithms Run In Realtime

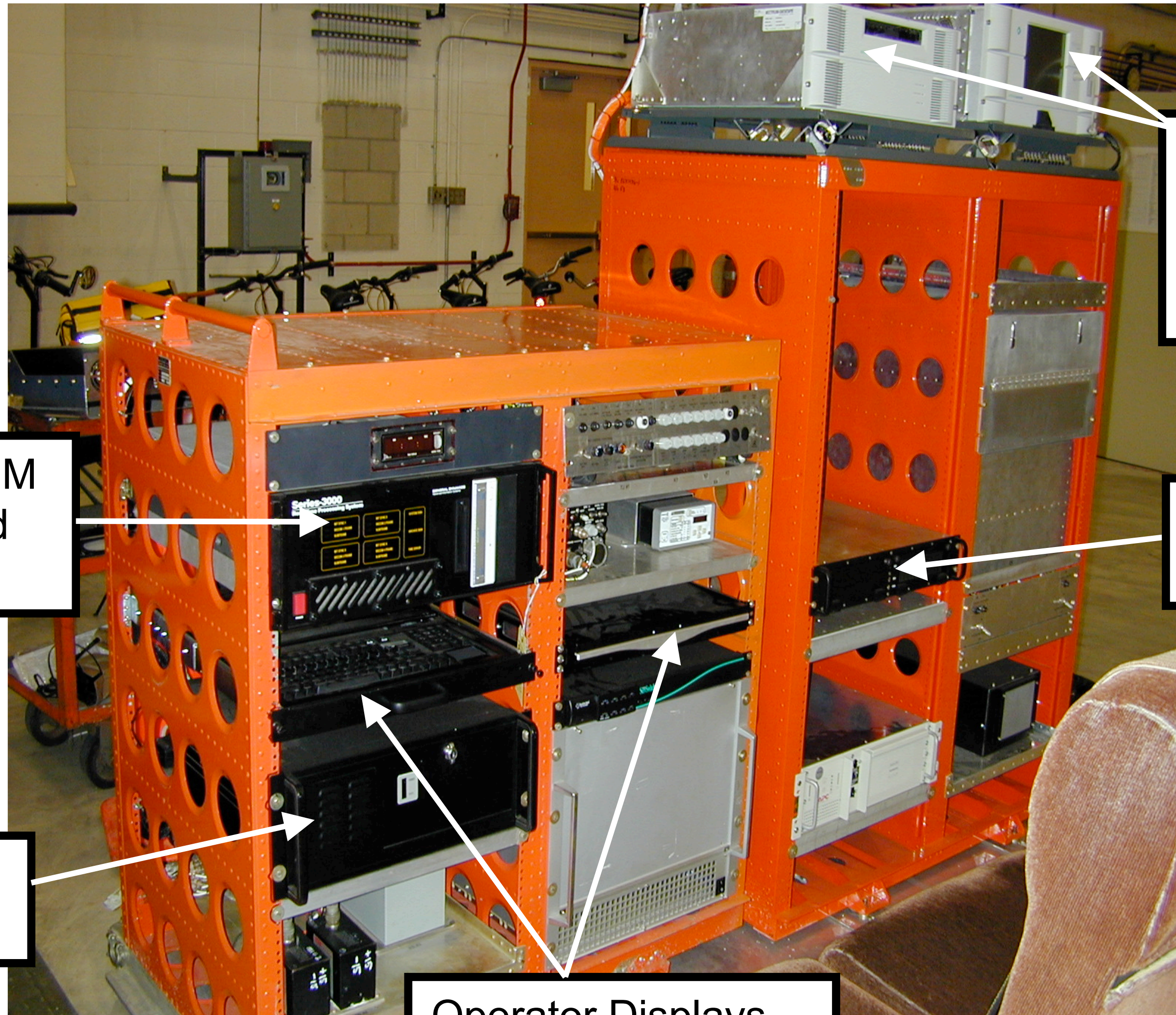
IVHM - Dryden's Role

- **Research/Test Vehicle**
  - Four engine transport with commercial type engines currently in use today
  - Long duration flights
  - Flights local or transcontinental
  - Diverse and austere airframe/engine operating environment

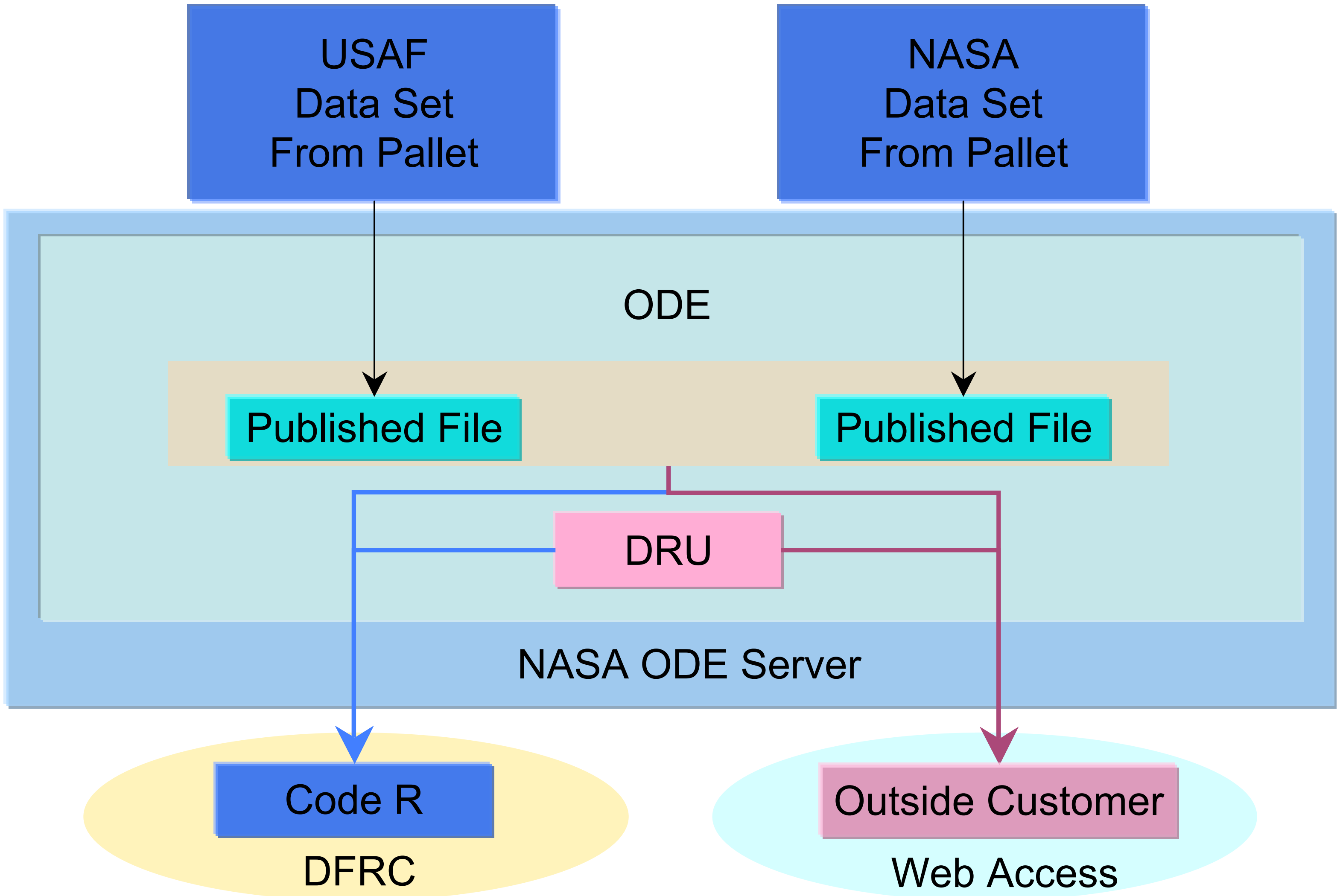
IVHM - Dryden's Role

- **Research engineering pallet (flying control room)**
  - Capable of aircraft and simulator interface
  - Real-time monitoring and in-flight playback
  - Embedded engine models running real-time
  - Can host and evaluate engine and prognostic control laws and algorithms
  - Integrated aircraft and engine data
  - Acts as virtual avionics sub-suite
  - Provides for data fusion, virtual sensors and metadata
  - Telemetry downlink upgrades planned
  - Can be relocated to other research team locations
- **Specialized engine instrumentation on research engine**
  - Hi/Lo speed data transmission from engine to airframe
  - Gas path
    - Inlet/Exhaust Debris Monitoring Sensors
    - Flight test certification suite installed
  - Mechanical
    - Hi/Lo Freq vibration sensors in several locations
    - Acoustic sensors
  - Growth for several other types of sensing for both mechanical and gas path research

NASA Onboard Instrumentation System Rack



Wyle Real-Time Processing System and
Omega Data Environment (ODE)



First Step Toward Feature Extraction

Installing Generic Engine Models Into Wyle System

- **Commercial Modular Aero-Propulsion System Simulation (C-MAPSS)**
  - Developed at NASA GRC
  - Code is a combination of Matlab and Simulink with GUI screens
  - Can simulate the response to engine faults and deterioration
    - Can add sensor and actuator dynamics, other inputs, and functions
  - Includes a comprehensive engine control system
    - Open loop or closed loop evaluations
    - Limit regulators to prevent exceeding engine design limits
    - Accel and decel limiters for the core speed
    - The fan-speed controller and 4 limit regulators are scheduled to perform over the entire flight envelope and power levels
      - These can be modified using the controller-design GUI which uses a Linear Engine Model (LEM) to represent the engine

First Step Toward Feature Extraction

Installing Generic Engine Models Into Wyle System

- **Convert the Matlab/Simulink model to C++ code using the Mathworks Real Time Workshop**
  - Code will be optimized using the Mathworks xPC Target
- **Install C-MAPSS in the NASA onboard rack (Wyle Telemetry Data System)**
  - Install as a “user-application”
- **Verify model operation using past flight data**
  - Wyle ODE greatly simplifies this task
- **Demonstrate a working C-MAPSS model using real-time flight data as inputs**
  - Create capability for users to modify inputs
  - Insert different fault types for analysis

Concluding Thoughts

- **In today’s aircraft operations environment, the amount of data generated is immense**
  - Time-based maintenance not condition-based maintenance
  - It is slow and cumbersome process to analyze data and provide feedback back to the fleet or airplanes
  - Prognostics is minimal, fault detection and accommodation is reactionary
- **Implementation of an IVHM research environment that allows**
  - Creation of adaptive, reconfigurable systems
  - Creation of feature extraction techniques
  - Hosting, development, and modification real time of models and algorithms
  - Fault detection research using real-time or post flight data
- **Successful operation of the C-MAPSS engine model with real-time flight input data will be a good first step toward real-time analysis of feature extraction methods**

Back Up Charts

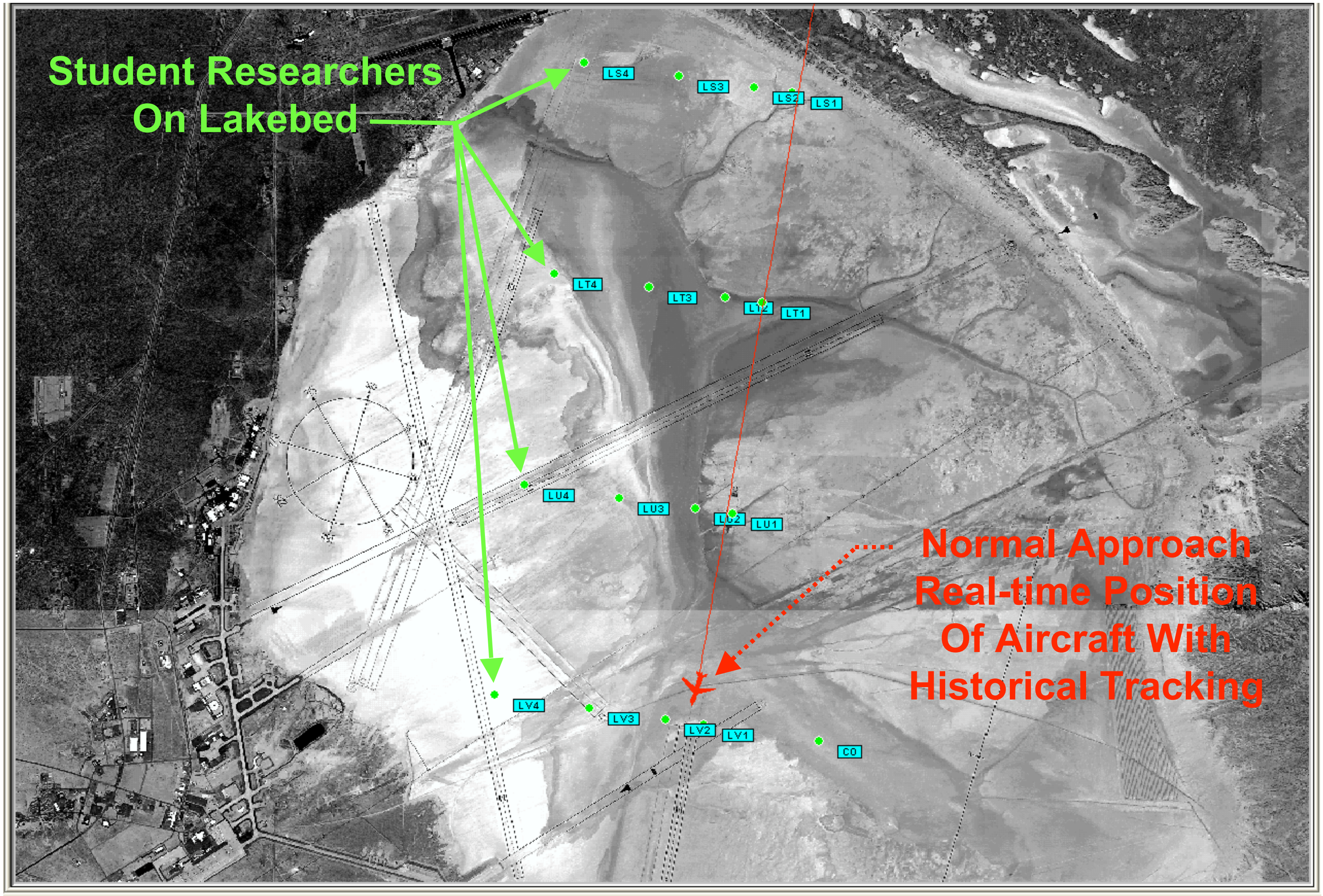
Prognostics and Mitigation

Real-Time Example

- **Noise Mitigation Smart Terminal Approach Technique (NMSTAT)**
  - Supporting ARC research activity
  - Airborne control room
  - Airplane crew (diverse)
    - DFRC Pilot/USAF Pilot
    - DFRC Flight Test Engineer
    - American Airlines pilot (observer)
    - 2 DFRC propulsion engineers
    - 1 ARC PI
  - Ground personnel
    - ARC PI
    - Up to 17 student researchers
    - Northrop Grumman acoustics engineer
    - Ground/Range Safety

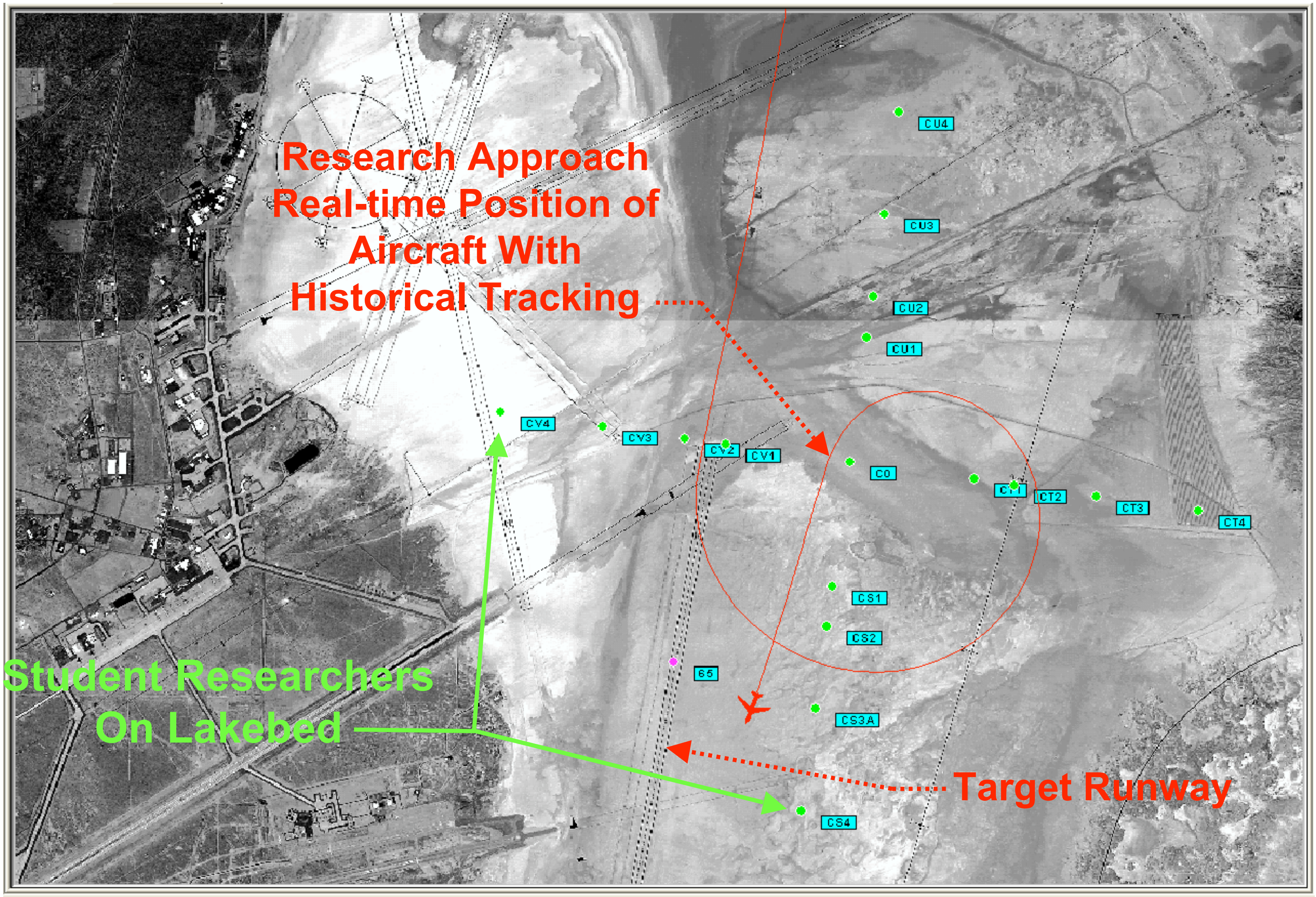
Real-Time Example

NMSTAT



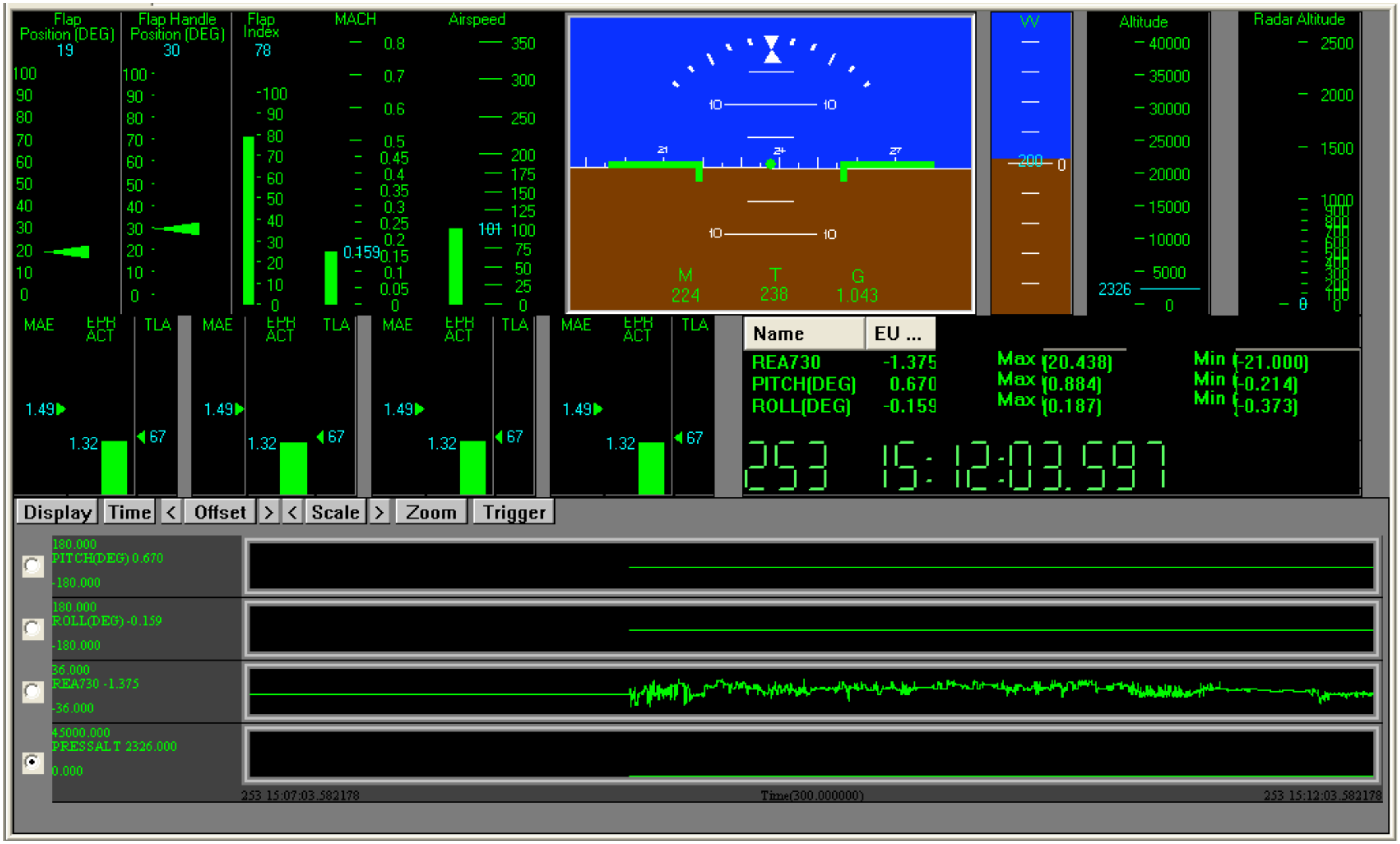
Real-Time Example

NMSTAT



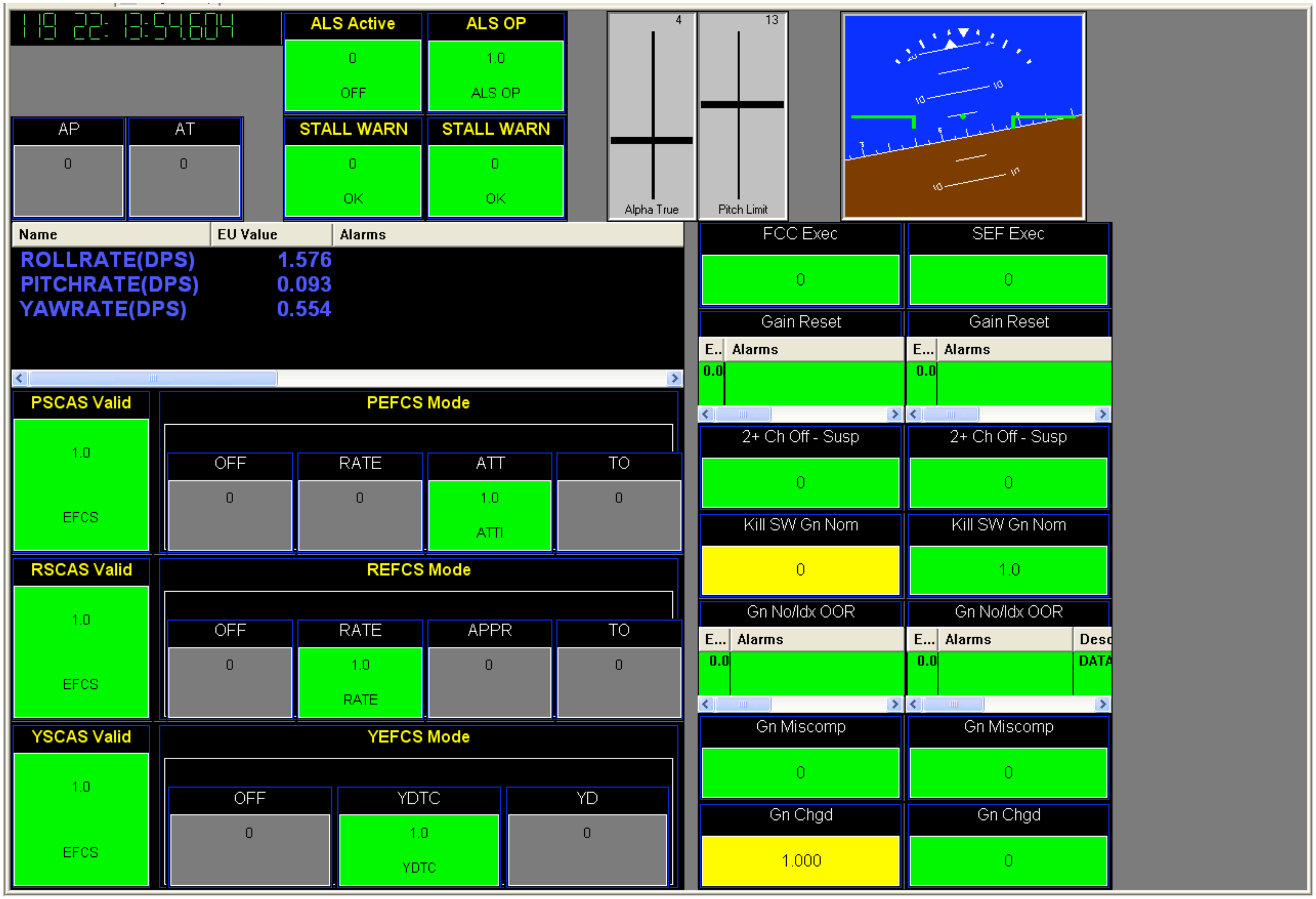
Real-Time Example

NMSTAT Display



Prognostics and Mitigation

Real Time – Throttles Only Control



NASA